Alexandria University
Faculty of Engineering
Electrical Engineering Department

ECE 336: Semiconductor Devices
Sheet 6

Chapter 10:

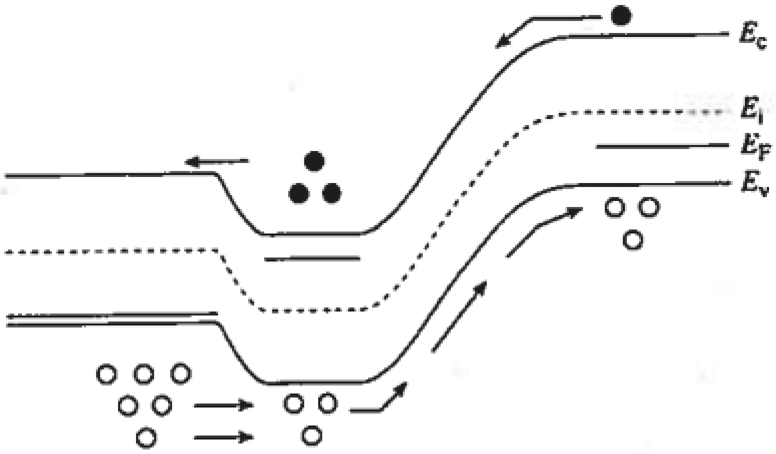
1. A Si pnp BJT with $N_{AE} = 5x10^{17}$ / cm^3, $N_{DB} = 10^{15}/cm^3$ and $N_{AC} = 10^{14}/cm^3$ and $W_B = 3\mu m$ is maintained under equilibrium conditions at room temperature.
    a. Sketch the energy band diagram for the device, properly positioning the Fermi level in the three regions.
    b. Sketch
        i. The electrostatic potential, setting V = 0 in the emitter region.
        ii. The electric field
        iii. The charge density.
    c. Calculate the potential difference between collector and emitter.
    d. Determine the quasineutral width of the base.
    e. Calculate the maximum magnitude of electric fields in the E-B and C-B depletion regions.

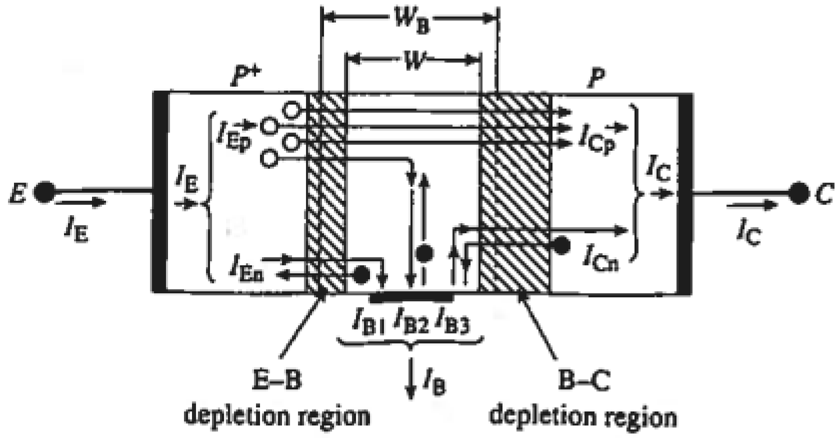
2. A Si npn BJT with $N_{DE} = 10^{18}$ / cm^3, $N_{AB} = 10^{16}/cm^3$ and $N_{DC} = 10^{15}/cm^3$ and $W_B = 3\mu m$ is maintained under equilibrium conditions at room temperature.
    a. Sketch the energy band diagram for the device, properly positioning the Fermi level in the three regions.
    b. Sketch
        i. The electrostatic potential, setting V = 0 in the emitter region.
        ii. The electric field
        iii. The charge density.
    c. Calculate the potential difference between collector and emitter.
    d. Determine the quasineutral width of the base.
    e. Calculate the maximum magnitude of electric fields in the E-B and C-B depletion regions.

3. Biases of $V_{EB} = 0.5V$ and $V_{CB} = -2$ V are applied to problem 1 BJT.
    a. Sketch the energy band diagram for the device properly positioning the Fermi level in the three device regions.
    b. Superimposed on the respective sketches completed in response to problem 1, sketch the electrostatic potential, electric field, and charge density as function of position.

4. For a typically doped Si npn transistor, sketch the energy band diagram, electrostatic potential, electric field and charge density inside the device as a function of position under active mode biasing.

5. A pnp BJT is saturation biased with $I_C > 0$. Construct figures similar to the following figures showing the carrier activity and diffusion currents inside the transistor.





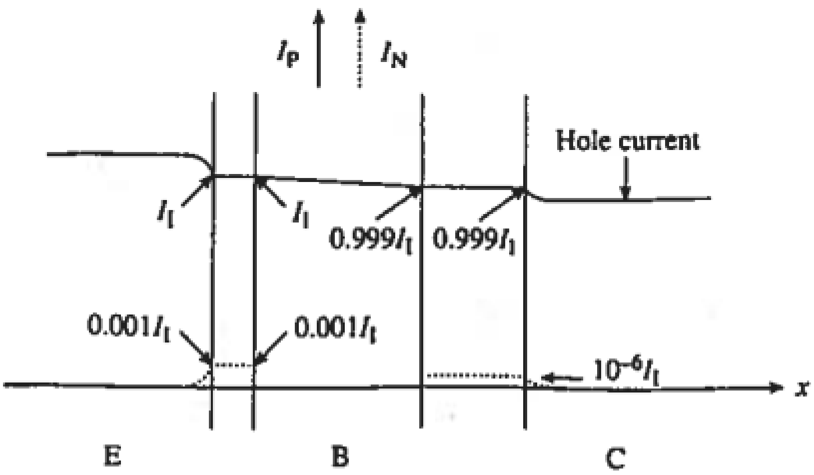
6. An npn is biased into cutoff. Construct figures similar to the preceding figures that show carrier activity and diffusion currents inside the transistor.

7. Given a pnp BJT where I_{Ep} = 1mA, I_{En} = 0.01mA, I_{Cp} = 0.98mA and I_{Cn} = 0.1µA, calculate:
   a. α_T
   b. γ
   c. I_E, I_C, I_B
   d. α_{dc} and β_{dc}
   e. I_{CB0} and I_{CE0}
   f. I_{Cp} is increased to a value closer to1mA while all other current components remain fixed. What effect does that have on β_{dc}? Explain.
   g. I_{En} is increased while all other current components remain fixed. What effect does that have on β_{dc}? Explain.

8. Given a pnp BJT where I_{En} = 100µA, I_{Ep} = 1µA, I_{Cn} = 0.99mA and I_{Cp} = 0.1µA, calculate:
   a. α_T
   b. γ
   c. I_E, I_C, I_B
   d. α_{dc} and β_{dc}
   e. I_{CB0} and I_{CE0}
   f. I_{Cn} is increased to a value closer to 0.1mA while all other current components remain fixed. What effect does that have on β_{dc}? Explain.
   g. I_{Ep} is increased while all other current components remain fixed. What effect does that have on β_{dc}? Explain.

Chapter 11:

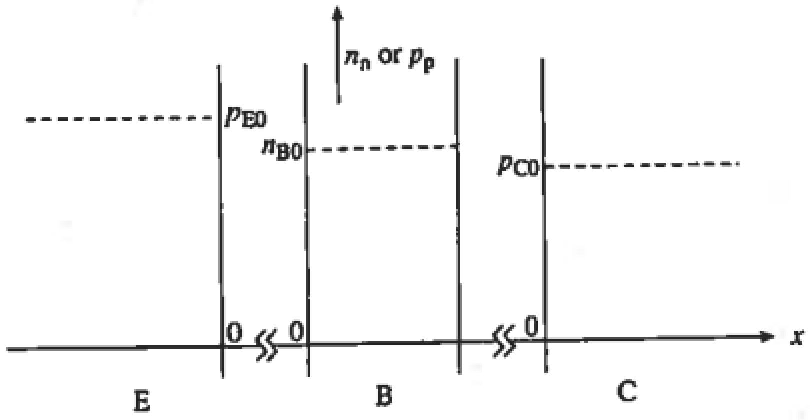
1. The electron and hole currents inside a pnp BJT biased in the active mode are plotted in the figure. All the currents are referenced to I_1, the hole current injected into the base. Determine:
    a. The emitter efficiency (γ)
    b. The base transport factor (α_T)
    c. The common emitter d.c. cuttent gain (β_{dc})
    d. The base current (I_B)
    e. For the given transistor, is the recombination-generation current arising from the depletion regions negligible as assumed in the ideal transistor analysis? Explain



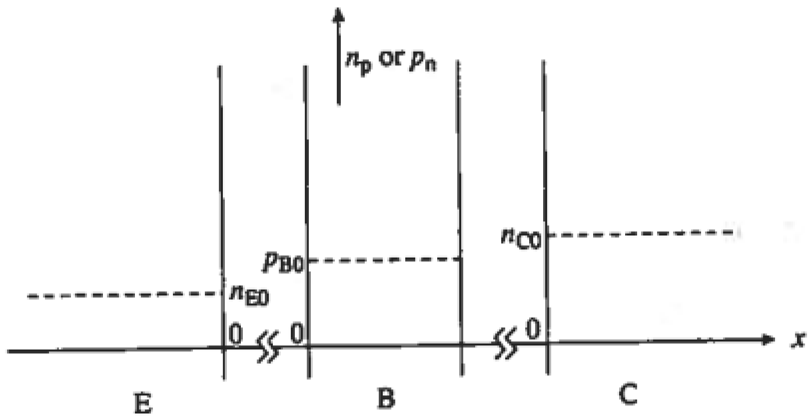
2. Examine how the minority carrier distribution in the base of pnp BJT varies with the W/L_B ratio. Taking $V_{CB} = 0$ so that $\Delta p_B(W) = 0$, construct a multicurve plot of $\Delta p_B(x)/\Delta p_{B0}(0)$ versus x/W corresponding to W/L_B = 10,5,1,0.5 and 0.1. Note that $0< \Delta p_B(x)/\Delta p_{B0}(0) <1$ and $0<x/W<1$. Comment on the plot.

3. The equilibrium majority and minority carrier concentrations in the quasineutral regions of the BJT are shown as dashed lines in the following figures. These figures are intended to be linear plots, with a break in the x-axis depletion regions to accommodate the different depletion widths associated with the various biasing modes. Note that the carrier concentrations in the three transistor regions are not drawn to the proper relative scale, but only qualitatively reflect the fact that $N_E >> N_B > N_C$. Employing solid lines and remembering the figures are intended to be linear plots, sketch the majority and minority carrier distributions in the respective quasineutral regions of the $W << L_B$ transistor under
    a. Active mode biasing.
    b. Inverted mode biasing
    c. Saturation biasing

d. Cutoff biasing

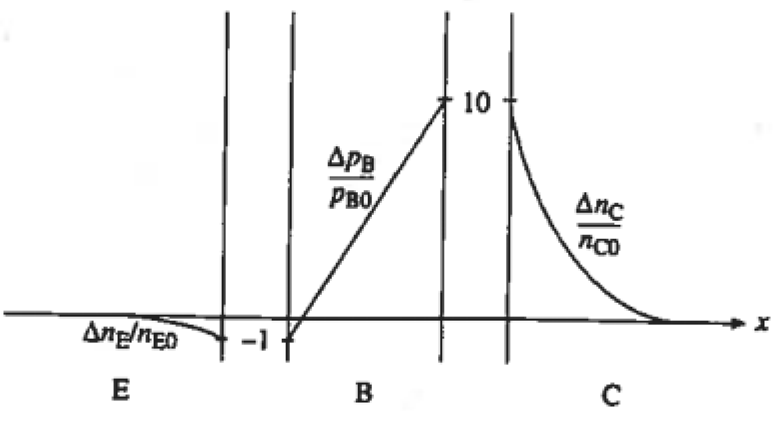


(a) Majority carrier concentrations



(b) Minority carrier concentrations

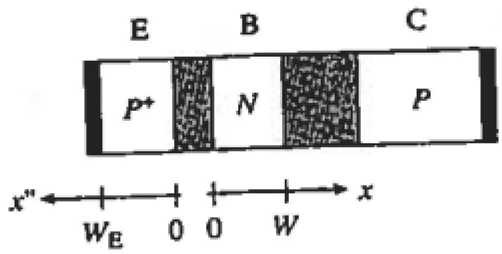
4. The $\Delta n_E/\Delta n_{E0}$, $\Delta p_B/\Delta p_{B0}$ and $\Delta n_C/\Delta n_{C0}$ distributions in the quasinetural regions of the pnp BJT are sketched in the following figure. Determine:
    a. The polarity of V_{EB}
    b. The polarity of V_{CB}
    c. The magnitude of V_{CB}
    d. The biasing mode
    e. Repeat for npn BJT.



5. Complete the below table by indicating whether the noted change in BJT device parameter increases, decreases or has no effect on the listed performance parameters.

Change	Effect on γ	Effect on α_T	Effect on β_{dc}
Increase W_B			
Increase τ_B			
Increase N_B			
Increase τ_E			
Increase N_E			

6. The emitter in modern BJTs is often made very thin to achieve high operating speeds. In this problem we examine the effect of employing a "shallow: emitter on the performance parameters. Consider the pnp BJT pictured in the figure where, like the base, the emitter is of finite width. Let W_E be the quasineutral width of the emitter and assume Δn_E=0 at the metallic emitter contact (x" = W_E).



   a. Paralleling the ideal transistor analysis, obtain revised expression of Δn_E I_{EN}.
   b. Established revised expressions for the performance parameters analogous to equations 11.31 – 11.34

$$\gamma = \frac{1}{1 + \left(\frac{D_E}{D_B}\frac{L_B}{L_E}\frac{N_B}{N_E}\right)\frac{\sinh(W/L_B)}{\cosh(W/L_B)}} \tag{11.31}$$

$$\alpha_T = \frac{1}{\cosh(W/L_B)} \tag{11.32}$$

$$\alpha_{dc} = \gamma\alpha_T = \frac{1}{\cosh(W/L_B) + \left(\frac{D_E}{D_B}\frac{L_B}{L_E}\frac{N_B}{N_E}\right)\sinh(W/L_B)} \tag{11.33}$$

$$\beta_{dc} = \frac{1}{\frac{1}{\alpha_{dc}} - 1} = \frac{1}{\cosh(W/L_B) + \left(\frac{D_E}{D_B}\frac{L_B}{L_E}\frac{N_B}{N_E}\right)\sinh(W/L_B) - 1} \tag{11.34}$$

   c. Extablish the revised expressions for the performance parameters when W/L_B <<1 and W_E/L_E <<1.
   d. Referring to the part (b) and (c) answers, how are γ and β_{dc} affected as W_E is systematically decreased?
   e. Make a sketch similar to figure 11.2 showing minority carrier distribution in shallow emitter (W_E/L_E <<1) under active mode biasing

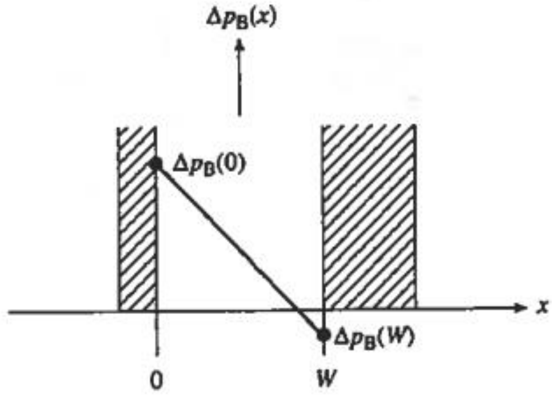
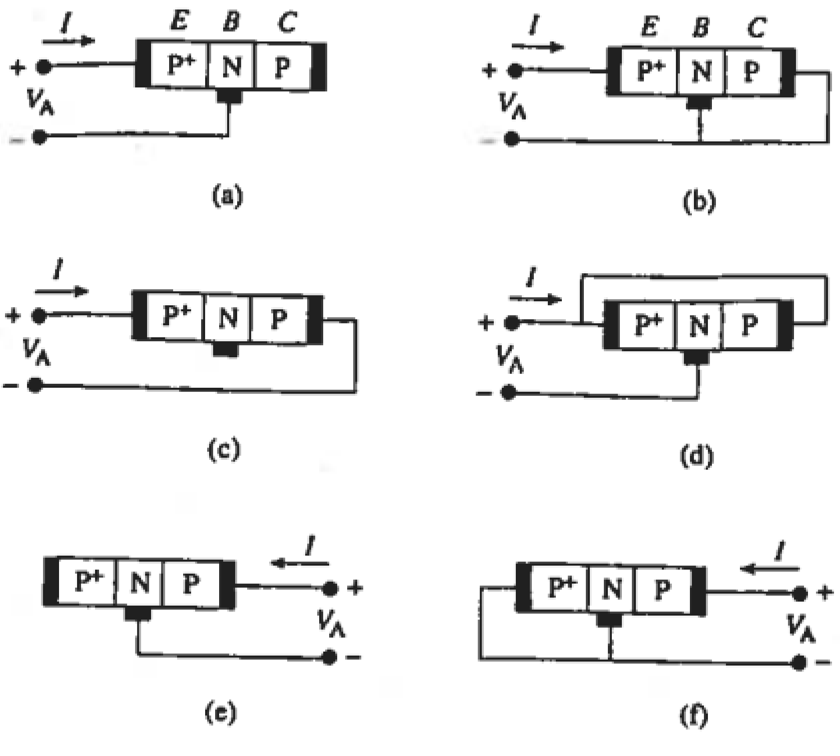


Figure 11.2 Perturbed carrier concentration ($p_B - p_{B0}$) in the base of a *pnp* BJT. The pictured distribution corresponds to active mode biasing ($V_{EB} > 0$, $V_{CB} < 0$).

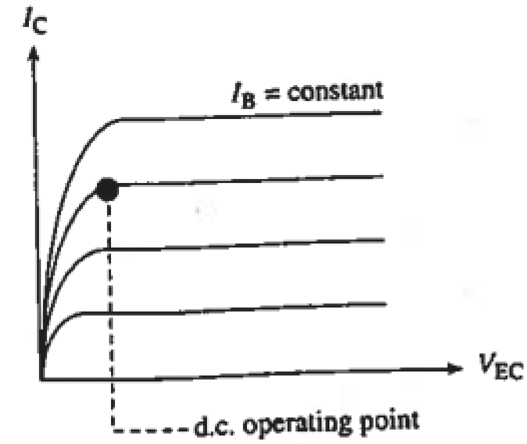
7. When one of the transistor terminals is left floating or two terminals are connected together, the transistor becomes diode-like or two terminal device. The six possible diode connections are pictured in the figure. Answer the questions that follow after choosing a specific connection for analysis. It is suggested that at least one open-circuit connection (a,c or e) and one short-circuit connection (b,d or f) be analyzed.



a. Derive the I-V_A relatinship for the diode by appropriately manipulating and combinig the Ebers-Moll equations. I should be expressed only in terms of V_A and the Ebers-Moll parameters.
b. Develop expressions for $\Delta p_B(0)/\Delta p_{B0}$ and $\Delta p_B(W)/\Delta p_{B0}$ in terms of V_A and the Ebers-Moll parameters.
c. Simplify the part (b) results by setting $\alpha_F = \alpha_R = \alpha$ and $I_{F0} = I_{R0} = I_0$. (The simplifications here would be valid for a transistor where the material parameters of the emitter and collector are identical.)
d. Utilizing the part (c) relationship and assuming $W \ll L_B$, sketch the minority carrier distribution in the base of the transistor if $V_A \gg KT/q$.

e. Repeat part(b) for a reverse bias where $-V_A >> KT/q$.

8. The common emitter output characteristics of a pnp BJT for small values of V_{EC} are pictured in the following figure. The DC operating point of the transistor lies at the boundary between active mode and saturation mode biasing as illustrated in the figure.



a. Referring to figure 11.3, draw the simplified large signal equivalent circuit for the transistor at the given operating point.

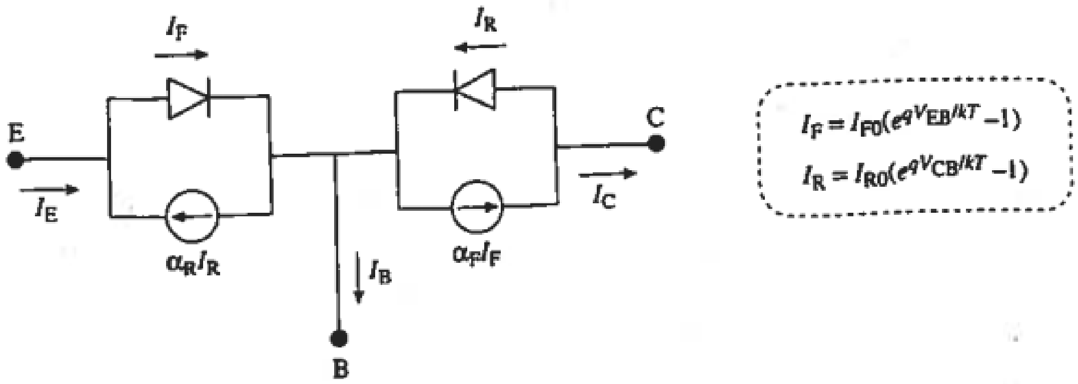


Figure 11.3 Large signal equivalent circuit for a *pnp* BJT based on the Ebers–Moll equations.

b. Employing the simplified equivalent circuit of part (a), or working directly with the Ebers-Moll equations, obtain an expression for V_{EC} at the specified operating point. Your answer should be in terms of I_B and the Ebers-Moll parameters.

9. The computational equations for the BJT characteristics quoted in Exercise 11.7 were established appropriately combining and/or rearranging the Ebers-Moll equations. Perform the algebraic manipulations necessary to derive the quoted equation for
   a. The common base output [$I_C = I_C(V_{CB}, I_E)$]
   b. The common emitter input [$I_B = I_B(V_{EB}, V_{EC})$]

c. The common emitter output [$I_C = I_C(V_{EC}, I_B)$]

(1) Common base input [$I_E = I_E(V_{EB}, V_{CB})$]

$$I_E = I_{F0}(e^{qV_{EB}/kT} - 1) - \alpha_R I_{R0}(e^{qV_{CB}/kT} - 1)$$

(2) Common base output [$I_C = I_C(V_{CB}, I_E)$]

$$I_C = \alpha_F I_E - (1 - \alpha_F \alpha_R) I_{R0}(e^{qV_{CB}/kT} - 1)$$

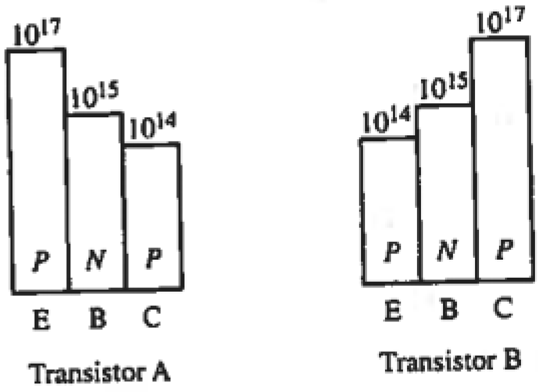
(3) Common emitter input [$I_B = I_B(V_{EB}, V_{EC})$]

$$I_B = [(1 - \alpha_F)I_{F0} + (1 - \alpha_R)I_{R0}e^{-qV_{EC}/kT}]\, e^{qV_{EB}/kT} - [(1 - \alpha_P)I_{F0} + (1 - \alpha_R)I_{R0}]$$

(4) Common emitter output [$I_C = I_C(V_{EC}, I_B)$]

$$I_C = \frac{(\alpha_F I_{F0} - I_{R0}e^{-qV_{EC}/kT})[I_B + (1 - \alpha_F)I_{F0} + (1 - \alpha_R)I_{R0}]}{(1 - \alpha_F)I_{F0} + (1 - \alpha_R)I_{R0}e^{-qV_{EC}/kT}} + I_{R0} - \alpha_F I_{F0}$$

10. Two pnp BJTs are identical except that the emitter and collector region doping are interchanged as illustrated in the figure.



a. Which transistor is expected to have the greater emitter efficiency? Explain.